Machine Process Capability Information

Through Six Sigma

Federal Manufacturing & Technologies

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ABSTRACT

A project investigating details concerning machine process capability information and its accessibility has been conducted. The thesis of the project proposed designing a part (denoted as a machine capability workpiece) based on the major machining features of a given machine. Parts are machined and measured to gather representative production, short-term variation. The information is utilized to predict the expected defect rate, expressed in terms of a composite sigma level process capability index, for a production part. Presently, decisions concerning process planning, particularly what machine will statistically produce the minimum amount of defects based on machined features and associated tolerances, are rarely made.

Six sigma tools and methodology were employed to conduct this investigation at AlliedSignal FM&T. Tools such as the thought process map, factor relationship diagrams, and components of variance were used. This study is progressing toward completion. This research study was an example of how machine process capability information may be gathered for milling planar faces (horizontal) and slot features. The planning method used to determine where and how to gather variation for the part to be designed is known as factor relationship diagramming. Components-of-variation is then applied to the gathered data to arrive at the contributing level of variation illustrated within the factor relationship diagram. The idea of using this capability information beyond process planning to the other business enterprise operations is proposed.

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Introduction

Recent improvements have been realized in the field of solid modeling with the ability to assign material properties to the model, and have true three- dimensional representation. These improvements enhanced development in such areas as automated process planning for machined features like slots, holes, and planar faces.

The lifecycle of a manufactured part is initiated with design part representation software (CAD) and progresses toward manufacture feature representation utilizing CAM software. The part is designed electronically as a solid model and is transmitted to the intended manufacturer. Using current, commercially available software, the recipient of the e-drawing may assign manufacturing and tolerance features to the part as per requirements. The result of these actions is a solid model with tolerances and manufacturing features from which NC software and process work instructions may be generated. These steps may be seen in Figure 1.

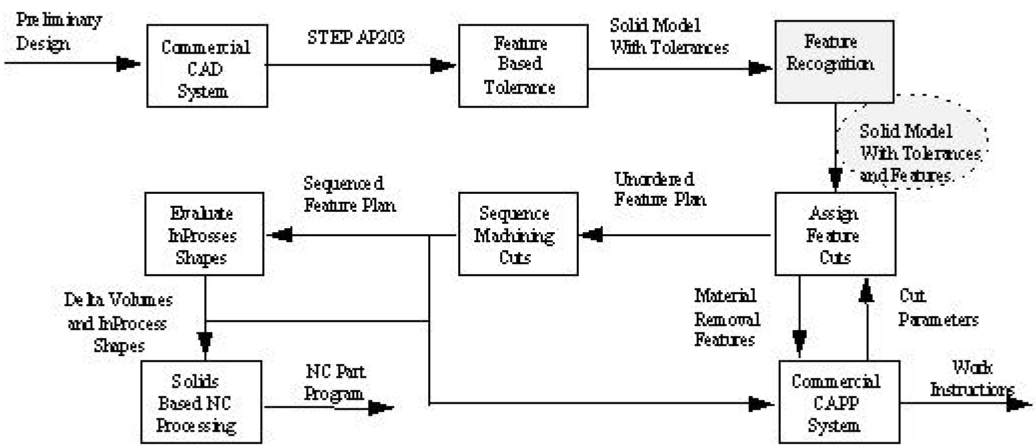

Figure 1: Solid Model, Tolerancing and Process Planning Flow [1]

The output of the steps in Figure 1 are the "whats" for producing a part but do not point "where" the parts may be made, i.e., machines ranked according to their process capability indices derived from the tolerances on the dimensional callouts of the feature. At this point within the part life machine process information is required.

The output of the feature recognition step in Figure 1 is a solid model with tolerances and features. This process capability information on the manufacturing machines is required not only by the designer, process planner, and manufacturing engineer, but also for marketing and management in order to function well in an agile and flexible business environment. A conceptual illustration of this idea is shown in Figure 2.

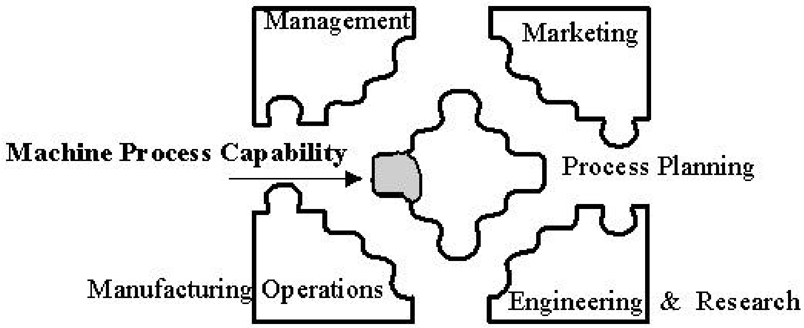

Figure 2: Manufacturing Business Model

Management may utilize this database to develop new missions and goals for future products (what is the company good at producing, and what machines in the plant have that capability).

This paper will examine the Six Sigma tools used to support this ongoing project investigating this machine process capability information resource. Specifically, thought process map, factor relationship diagrams, and components of variance will be discussed.

Project goal and Paper Overview

The main objective of the project is to develop a machine capability information resource based upon a specifically designed, representative part (called machine process capability workpiece) for process variation encountered during horizontal face milling and slot milling operations on a three-axis milling machine. Additionally, the capability information resource will have the ability to predict an expected defect rate for a feature of a given "production" part based upon component variance data of the machine process capability workpiece.

This paper will take an abbreviated overview of the project and use only the slot milling process for illustrative purposes.

Recall that product (process) variation may be expressed as Equation 1

$$s^2_{total} = \{\sigma^2_{\underline{machine}} + \sigma^2_{material} + \sigma^2_{operator} + \sigma^2_{methods} + \sigma^2_{environ.}\} + \sigma^2_{measure} \quad \text{(Eq. 1)}$$

This project concentrates on those process parameters (factors) which are related to the variation of the machine. For this study that includes tooling, machine setup, spindle horsepower (combining the interdependent factors of material feedrate, spindle rotational speed, and depth of cut), and various time intervals over which parts are being produced. Traditionally, feed, speed, and depth of cut are examined independently. Other process parameters recognized as affecting the product quality output of a milling machine include: part material, tool wear, tool cutting fluid, workpiece rigidity, part holding fixture, machine operator, temperature, and the measurement system. These parameters are monitored but are considered as noise in the process, and are not differentiated in this study.

The high-level sequence of activities and tasks associated with this machine process capability project are:

The thought process map guided selection of what milling processes to select for further investigation and why, and in turn defining the scope of work. The factor relationship diagram method assisted in:

* Where to study the variation in the feature-producing steps of machining,

* What process factors to control,

* What factors to consider as noise to the machining process, and

* What changing factors on which to collect process information.

The machining schedule for the capability workpiece and the production part could then progress to produce a project schedule. Once the project schedule was established for the two separate run of parts, resources could be assembled to carry out the actual machining portion of the project.

Components of variation method will assemble the individual sigmas for each contributing element of the feature (slot). This feature was produced on the machine process capability workpiece to achieve an overall sigma level machine process capability index for that feature in relationship to the given part under consideration for manufacture.

thought process map and factor relationship diagram (FRD) method

The structure of the machining project plan for this research was driven by what is called a thought process. A thought process map is one method to develop the right questions to ask in order for the original objective to be satisfied as a result of the answers ascertained.

"Start with the end in mind" very much applies to this project. The thought process map which was used to guide design, to machine, to measure and to analyze the parts produced in this study is illustrated in Figure 3.

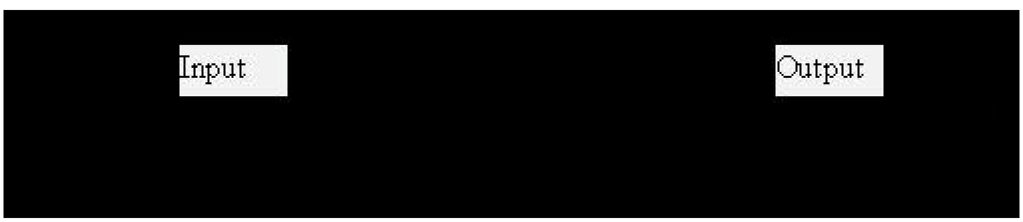

Figure 3: Thought Process Map - Machine Process Capability Project

What processes to select, in conjunction with what information and the structure of that information, were considered at a very high level. Initial ideas for the type of information needed began with the activities in the automated process planning for manufacturing. These ideas led to formulating a pragmatic method of capturing variation for machining operations, and applying the resultant sigma level capabilities in the process planning operation.

Issues under consideration at the conceptual phase of this project were funding, location to manufacture parts, what processes to examine, what process factors to use to capture variation, length of project, sample size of machine process capability parts (how many to produce for sound statistical results), how to pick specific milling machine features (face milling, slotting), and what type of measuring techniques to use, to name but a few.

The second block deals with what type of process information and how to capture this information. Milling operations were selected during conceptualization because of previous work and projects in this area.

For the machining project, face milling and slotting processes were selected because:

* High frequency use in plant milling operations,

* Availability of a machine to perform this project work, and

* Extensive use by aerospace industry.

Next step is to look at what variation you want to capture for the factors which are critical to the process, keeping in mind the goal (for this project, the estimated sigmas for the face and slot milling operations). Types of variation are: measurement error, within part variation, between part variation, within a manufacturing day variation, between days' variation, between weeks' variation, between machine level settings' variation, within fixture setup variation, and between fixture setup variation.

The top level is a specific machine, a Cortland Monarch, 15 hp milling machine. This is not to say that variation does not occur from one milling machine to the next milling machine because this is always true, it is just a matter of degree. With this at the top of the subgrouping tree, different types of variation can be collected.

How the process information will be captured is through the use of the Factor Relationship Diagrams. The Factor Relationship Diagram (FRD) is a decision tool in the sense it assists in choosing where to allocate variation within a structure suited to the problem definition. In a sense variation is layered according to what process information is being sought. The FRD graphically displays the hierarchy of variation for a given process. The granularity for the estimate of the variation of the process can be ascertained by the number of levels; the more levels, the better the estimate of that piece of the process that contributes to the total variation of the process.

What will this structure look like for a slot milling operation, for instance? This tree structure will look different depending on the branches taken. For this project, the slot FRD is seen as Figure 4.

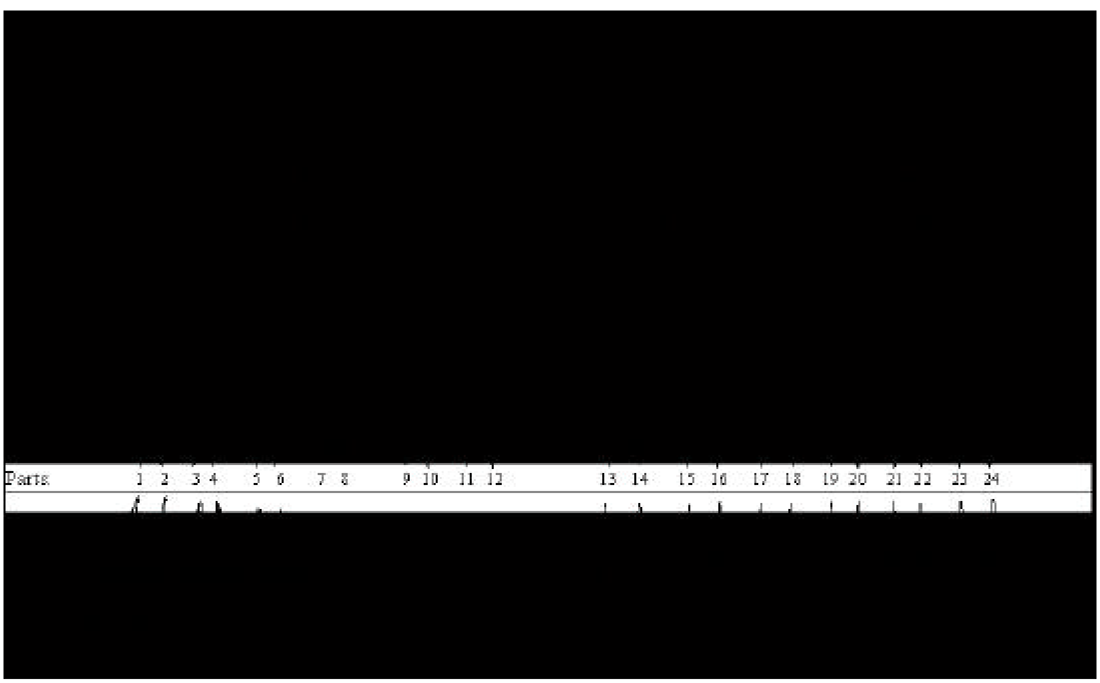

Figure 4: FRD for Slot Mill Process

What are the dimensions critical to defining a slot? These are noted on the FRD. They are: the width between the side faces formed by the tool, the depth of the bottom face from the cutting reference, the varying path of the tool (contour), and finally the location of the slot on the overall part itself (center line location from reference surface). Therefore, to estimate the sigma for a feature called slot, sigmas must be calculated and properly combined. This may be seen in Equation 2.

$$\sigma_{slot} = [\sigma^2_{\text{width of slot}} + \sigma^2_{\text{depth of slot}} + \sigma^2_{contour} + \sigma^2_{location}]^{1/2} \quad \text{(Eq. 2)}$$

The part was designed upon completion of the FRD. The machine process capability workpiece is intended to capture as much machine variation as possible. Throughout the project the same operator and his modus operandi were employed. The designed part has horizontal slots which vary in length as well as width (same depth of cut for all slots), and the same types of slots are oriented as well in the vertical cut direction with respect to the machine. This part may be seen in Figure 5.

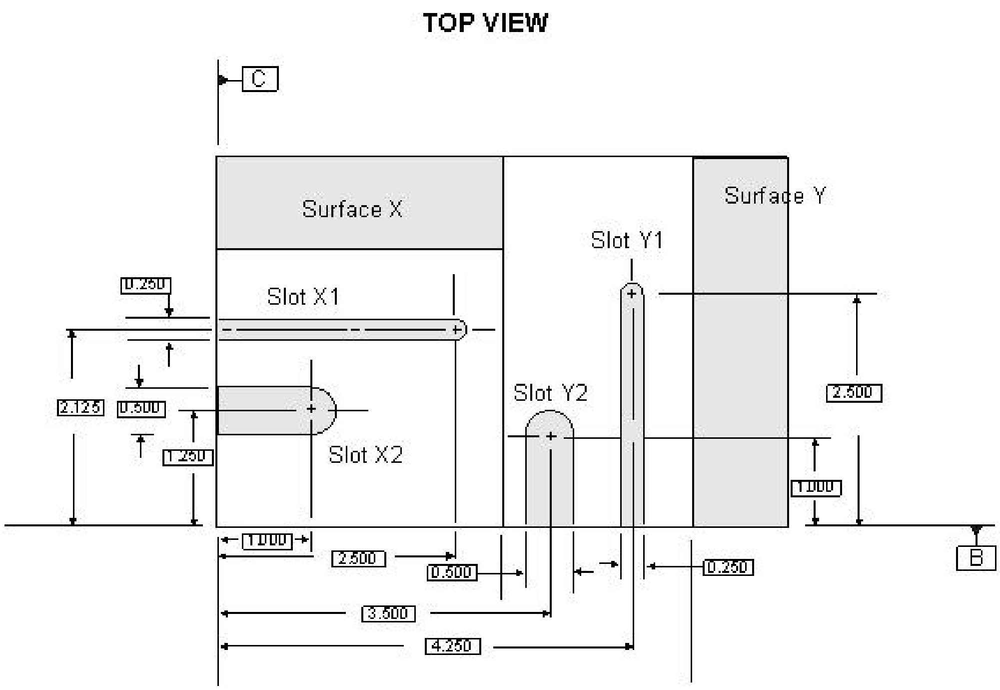

Figure 5: Machine Process Capability Workpiece

Components of Variation

Components of variation then takes the overall variation and parcels it into these layers seen in FRD. The lowest level of variation begins with the measurement system error and its contribution to overall variation. Simply stated, if the measurement system is not discriminating enough to detect changes in the manufactured parts, then process information begins on an unstable foundation.

The concept of components of variation is central to establishing the major contributors of variation and the elements of the process where variation may be found.

$$[\sigma^2_{total} = \{\sigma^2_{\underline{machine}} + \sigma^2_{material} + \sigma^2_{operator} + \sigma^2_{methods} + \sigma^2_{environ.}\} + \sigma^2_{measure}]$$

Again, Equation 1 (shown above) conveys the high level model of "components" - sources of variation. Typical components of variance are measurement error, within part variation, between part variation, within a manufacturing day variation, between days' variation, between weeks' variation, between machine level settings variation, within fixture setup variation, and between fixture setup variation. In the slot process, horse power was selected as a factor because it combines three common process factors (which are, in fact, interdependent), namely, feed, speed, and depth of cut. The variation captured using horsepower as a factor rather than the various level settings for feed, speed, and depth of cut is the broader applicability of the results for both planning and predictive purposes.

Results

Analysis on the reduction of product flow time has not been addressed but if upfront planning is done using the results of this proof-of -concept project, then product cycle time should be reduced.

Additionally, defects should be reduced with the knowledge of the machine capabilities known during the planning phase and not discovered until production.

About the author

Michael is currently the plant program lead for a Software Quality Assurance at the AlliedSignal Federal Manufacturing & Technologies, in Kansas City, Missouri. Michael has attained this level over the past ten years by working closely with the numerous developers, maintainers, and purchasers of software throughout the plant, and remaining current with software issues.

Currently, Michael is involved with a manufacturing project dealing with a machine process capability information resource, utilizing Six Sigma tools acquired during his training and certification. He received his certification in October 1996. He also is working on mapping the system integration of the product definition management process.

Michael holds a Masters of Science degree in Mechanical Engineering (1979) from the University of Missouri-Rolla, and a Bachelor of Science degree (cum laude) in Aerospace Engineering (1977) from the same institution. He is formally enrolled in the Doctor of Engineering program (January 1994) at the University of Kansas, specializing in the area of computer-aided and computer-integrated manufacturing.